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AN ASSESSMENT OF THE EFFECT OF THE FUEL COMPOSITION ON THE ATMOSPHERE OF DIESELIZED UNDERGROUND MINES.

A FINAL REPORT FOR D.S.S. CONTRACT

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INTRODUCTION

The introduction of diesels into underground mines has increased the concentrations of several different pollutants in the mine air (1). This arises because several gaseous pollutants such as CO_2, CO, NO, NO_2, and SO_2 are emitted by the diesels. In addition, respirable-sized particulate (2), sulfuric acid (3,4) and unburned hydrocarbons and hydrocarbon derivatives (5-7) are also released by the diesel. The presence of these pollutants in the mine environment has caused concern in the industry for some time because miner's working on, or downstream from a diesel are exposed to higher concentrations of these pollutants. Although previous work has shown that most of these pollutants do not exceed the threshold limit concentrations in the mining environment (1,7), there is still concern about the concentrations of sulfuric acid, diesel particulate and two types of hydrocarbons, the polynuclear aromatic hydrocarbons (PNAs or PAHs) and the nitrated polynuclear aromatic hydrocarbons or nitro-PAHs. The presence of PAHs in the mine environment is of concern because several of these compounds are known carcinogens (8,18). The nitro-PAHs cause concern because these compounds are highly mutagenic in the Ames Salmonella bioassay (7,11-16).

A great deal of time and effort has been expended in recent years in an effort to find a method of improving the air quality in dieselized underground mines. This interest has centered around determining a strategy for reducing the amount of particulate, the PAHs and the mutagens (primarily the nitro-PAHs) in the diesel exhaust.

Several different methods for reducing the concentrations of the mutagens and carcinogens in the mine air have been investigated. One approach has involved adding a catalytic converter to the exhaust system. Although preliminary tests on a new catalytic converter suggest that these devices might

be able to reduce the amounts of PAHs and nitro-PAHs in diesel exhaust (18), none of the catalytic converters currently in use improve the overall air quality, ie., the catalysts reduce the CO concentrations in the exhaust markedly but increase the amount of sulfuric acid, the PAHs and the mutagenicity of the exhaust (7). Thus, the overall effect of adding a catalytic converter is to decrease the concentration of a pollutant that is usually present in very low concentrations and to increase the concentration of the more harmful pollutants in the mine air. As a result, this strategy does not look promising.

A second approach has involved designing new filters that can be added to the exhaust train of a diesel. This approach seemed attractive because it was believed that the PAHs and nitro-PAHs were strongly absorbed onto the particulate in the exhaust. Thus, it was expected that a filter that removed the particulate would also remove the PAHs and nitro-PAHs from the exhaust. One of the filters that has been extensively tested is the University of Waterloo - U.S.B.M. filter. Although this filter reduces the amount of particulate in the exhaust significantly, preliminary experiments (7) suggest that it does not reduce the PAH concentrations, ie., that the PAHs were not removed with the particulate. Presumably, this filter does not remove the nitro-PAHs either.

More recently, preliminary tests on a new ceramic filter produced by the Corning Glass Company have shown (19) that this filter is capable of removing 88 to 95% of the particulate from the exhaust. In addition, the soluable organic fraction, the PAHs and the mutagenicity (the nitro-PAHs) are also reduced significantly by this filter (20). Similar results have been obtained in field trials in underground mines (21). Thus, this approach shows considerable promise and these filters are currently undergoing further tests.

A third strategy for reducing the PAHs and nitro-PAHs in diesel exhaust was to develop a low PAH fuel that could be burned in a diesel engine. This approach seemed attractive because several experiments (7,22) had suggested that the majority of the PAHs in the exhaust were PAHs that did not burn when the diesel fuel was ignited in the engine. Low concentrations of PAHs would be expected in the exhaust from a low PAH fuel because there are less PAHs per liter in a low PAH fuel, ie., if the amount (percentage) of PAHs burned in a particular engine were the same for different fuels, there would be fewer unburned PAHs in the exhaust from a low PAH fuel. Lower concentrations of nitro-PAHs would also be expected when a low PAH fuel was burned in the diesel because there would be fewer PAHs to react with NO_2 in the exhaust system, ie., a low PAH fuel would reduce the concentration of one of the reactants (the PAHs) required to make the nitro-PAHs. Thus, fewer nitro-PAHs would be produced and the exhaust would be less mutagenic. In this study the concentrations of the mutagens and the PAHs in the exhaust from a diesel engine burning three different diesel fuels were determined in order to learn whether changing the fuel would reduce the concentrations of these pollutants and improve the air quality in dieselized underground mines.

RESULTS AND DISCUSSION

Types of Fuels

Three different diesel fuels were examined in this study. One of the fuels tested was the Falconbridge #1 diesel fuel. This fuel was the low sulfur, number 1 grade diesel fuel normally used in Falconbridge Nickel Mine's Lockerby Mine. It was purchased in the Sudbury area from Imperial Oil Ltd.

The second fuel, called a 1990 fuel, was a heavy duty diesel fuel that had been obtained by refining Alberta Tar Sands crude oil. This fuel was chosen because it was high in aromatics and presumably in polynuclear aromatic hydrocarbons (PAHs). This fuel was also of interest because it is the fuel of the future, ie., it will form a larger percentage of the fuels used when Canada becomes more energy self-sufficient in the 1990s.

The third fuel was a Jet-A1 fuel that was purchased from Shell Oil in Sudbury. This fuel was chosen because previous work (22) had shown that Jet-A1 fuel contained lower concentrations of PAHs than the diesel fuels available in the Sudbury area.

Thus, this study involved examining a diesel fuel that was thought to be high in PAHs (the 1990 fuel), a commercial diesel fuel with an intermediate PAH content and a fuel that was low in PAHs (the Jet-A1 fuel) in order to learn how the PAH concentrations and the mutagenicity of the exhaust were influenced by the fuel burned in the diesel engine. The actual properties and the PAH content of the three fuels were determined so that the relationship between the PAHs in the fuel and those in the exhaust could be established.

Experimental Design

The actual experiments involved collecting exhaust samples downstream from a single, 180 horsepower, indirect-injection, air-cooled, F8L-714 series Deutz diesel. All of the exhaust samples were collected in the same location and the LHD cycle was identical for all three fuel tests.

The diesel was prepared for each test in the same manner. Before each fuel was put into the diesel, the fuel tanks and the crankcase were drained. Then, the fuel tank was refilled with the new fuel and fresh Esso HD-30 lubricating oil was added to the crankcase. In addition, the pre-cleaners on the Fram 248 PLD dry type intake filters were changed. Then, the engine was adjusted so that it delivered the same power on the new fuel. This entailed adjusting the stall speed (converter stall) to 2100 RPM, the high idle to 2300 RPM and the normal idle to 700 RPM. Finally, the engine was run for between two and four hours before any testing was begun. This was done to burn off any low boiling PAHs in the oil and to ensure that any traces of the old fuel were burned before the test on the new fuel was begun.

The other characteristics of the diesel engine used in these tests were; 1) the engine timing was 24 degrees BTDC, 2) the fuel setting on the regular #1 diesel fuel used at Lockerby mine was 88 cc/1000 strokes and 3) no exhaust treatment devices were used during these tests so that the true effect of changing the fuel could be determined. Finally, 4) the engine that was used in these tests had only been run for 377 hours before the tests were started. Thus, the engine was almost new and was in excellent condition.

Sample Collection

The actual experiment involved collecting exhaust samples downstream from a single, 180 horsepower, F8L-714 Deutz diesel working on the 2700 foot level at Falconbridge Nickel Mine's Lockerby Mine. The level plan for the 2700 foot level, the sampling sites and the path of the diesel are shown in Figure 1. The ventilation during the sampling ranged from 28,000 cfm to 29,600 cfm (151 to 160 cfm/brake horsepower), Table 1. The same diesel was used and the path of the diesel (the LHD duty cycle) and the sampling sites were identical in all three tests. The only variation was that two different scoop tram operators drove the diesel during the sampling. However, the LHD duty cycles for each driver were almost identical, ie., the duty cycle was approximately 2.6 minutes for each operator and changing the operators did not seem to affect the results significantly (vide infra).

In the LHD duty cycle, Figure 1, ore was carried in both directions. The loading at the muck pile nearest the sampling site (muck pile A) was a true mucking operation with a short (approximately 15 second) lug down. At the muck pile in the stope (muck pile B), the ore was dumped and then picked up again, carried back to muck pile A and dumped. Because the ore was not in front of a solid wall at muck pile B, the diesel could not be forced into the muck pile at maximum power. As a result, there was no lug down during the loading at muck pile B. Muck piles A and B were situated so that the exhaust ports of the diesel remained in the main drift throughout both of the loading operations. This ensured that all of the exhaust from the diesel passed the sampling sites.

The Hi Vol samplers that were used to collect the exhaust samples were placed on one meter high, 45 gallon drums to ensure that no particulate matter was drawn onto the filter from the floor of the drift. The Hi Vols were fitted with

Scale 1 cm. = 3.2 m.

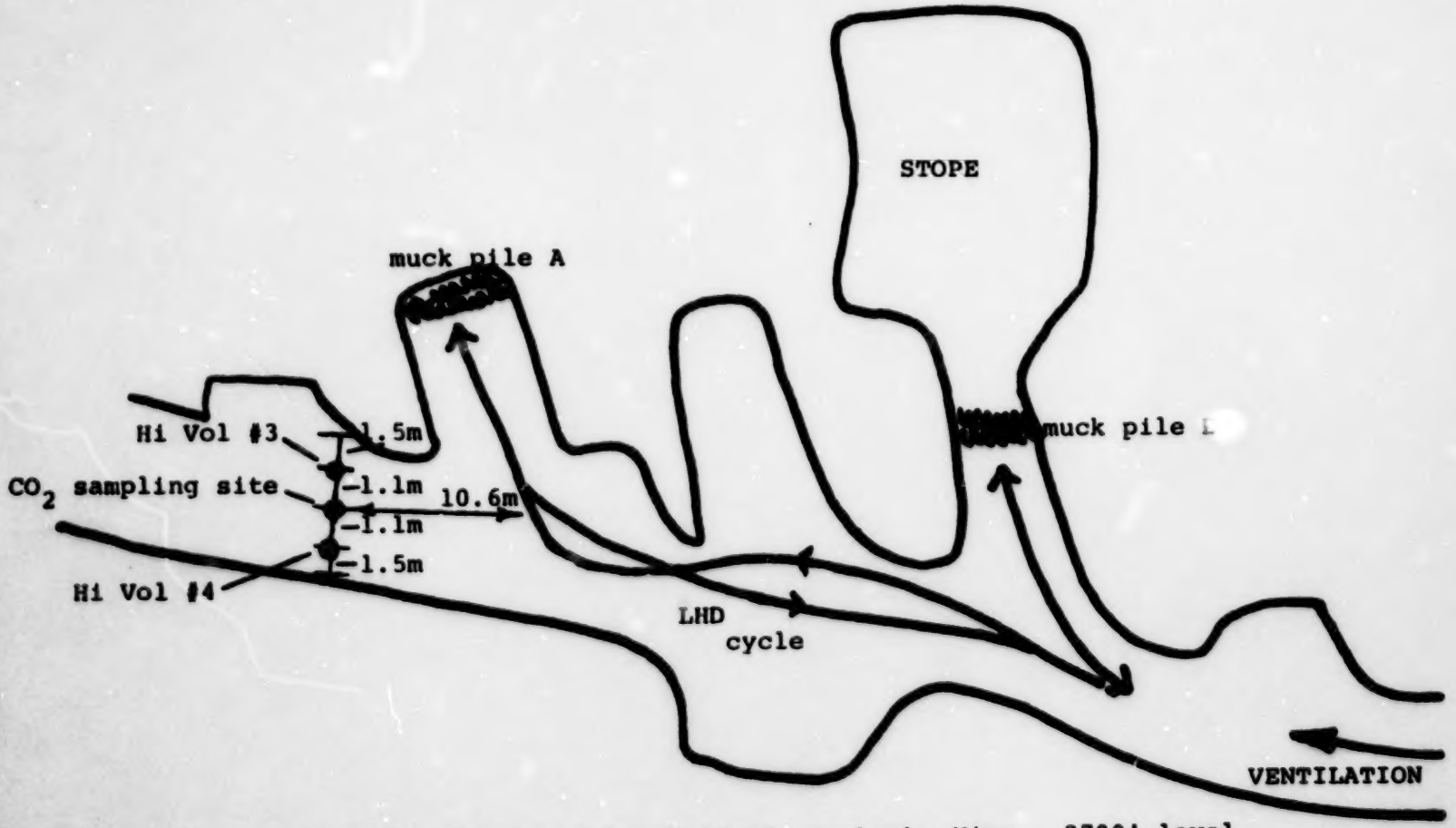

Figure 1. Sampling Site at Falconbridge's Lockerby Mine 2700' level

Table 1. Sampling times, ventilation rates, volumes of air sampled and the scoop tram operators for each type of diesel fuel.

Date	Ventilation cfm	Ventilation (cfm) Brake Horsepower	Sampling Time(min.)	Average Vol. of Air Sampled (cfm/min.)	Total Vol. of Air Sampled (m^3)	Hi Vol. Number	Scoop Tram Operator	Type of Fuel Burned
Dec 13-A	28,500	154	77	63.8	139.0	3	1-36 min. 2-41 min.	Falconbridge #1 Diesel
Dec 13-B	28,500	154	77	63.3	137.9	4	1-36 min. 2-41 min.	Falconbridge #1 Diesel
Dec 13-C	28,500	154	64	62.9	113.9	4	1	Falconbridge #1 Diesel
Dec 14-A	29,600	160	41	62.3	72.3	3	2	1990
Dec 14-B	29,600	160	41	62.9	73.0	4	2	1990
Dec 14-C	29,600	160	70	61.5	121.9	4	1	1990
Dec 14-D	29,600	160	57	62.6	101.0	4	1	1990
Dec 14-E	29,600	160	70	62.0	122.9	3	1	1990
Dec 14-F	29,600	160	57	63.1	101.8	3	1	1990
Dec 15-A	28,700	155	46	62.5	81.4	3	2	Jet A-1
Dec 15-B	28,700	155	65	63.0	116.0	3	2	Jet A-1
Dec 15-C	28,700	155	65	62.9	115.8	4	2	Jet A-1
Dec 16-A	28,000	151	62	63.0	110.6	4	1	Jet A-1
Dec 16-B	28,000	151	42	65.8	78.3	3	1	Falconbridge #1 Diesel
Dec 16-C	28,000	151	42	62.5	74.3	4	1	Falconbridge #1 Diesel
Intake Air	-	-	885	60.0	268.4	-	-	-

8 X 10 inch Pallflex T60-A20 teflon-coated fiberglass filters and placed on the barrels on the right and left sides of the drift, with the filters facing up the drift, ie., towards the diesel, Figure 1. The front of the Hi Vol samplers were approximately 11 meters from the closest approach of the diesel. The flow rate through the Hi Vols was recorded at the beginning and the end of the sampling period. The sampling was stopped when the flow rate through the Hi Vol sampler had decreased by twenty percent, ie., was approximately 80 percent of the original value. Then the filters were removed from the Hi Vol, folded so that the particulate was on the inside of the filter, sealed in a sterile polyethylene bag and stored in the dark in a freezer until they could be analyzed.

The details of the sampling, ie., the ventilation rates, the Hi Vol position, the scoop tram operator, the type of fuel, the sampling times and volumes of air sampled are given in Table 1.

The instantaneous concentrations of various gaseous pollutants (CO, NO_2, the total nitrogen oxides ($NOx = NO + NO_2$), SO_2 and CO_2) were measured at the CO_2 sampling site, Figure 1, with Draeger-type sampling tubes at various times throughout the sampling period. In addition, a time-weighted-average percent CO_2 sample was collected on top of the one meter high, 45 gallon drum situated at the middle of the drift between the Hi Vol samplers, ie., at the CO_2 sampling site. The time-weighted-average percent CO_2 samples were used to calculate the dilution ratio of the exhaust at the sampling site. The instantaneous concentrations of the gaseous pollutants, the CO concentrations in the raw exhaust, the temperature, the time-weighted-average percent CO_2, the dilution ratio and the percent relative humidity at the CO_2 sampling site are given in Table 2.

Table 2. The instantaneous concentration of the gaseous pollutants at the CO_2 sampling site, the temperature and the exhaust dilution ratio at the Hi Vol sampling sites for the various fuels.

Date	Instantaneous Concentrations in ppm. CO	NO_2	NO_x	SO_2	CO Raw Exhaust Right	CO Raw Exhaust Left	% CO_2 Instantaneous	Time-weighted average % CO_2	Temperatures at the sampling site (°C)	% Relative Humidity	Dilution* Ratio	Type of Fuel Burned
Dec 13	4	0.2 0.17	N.M.	N.D.	80	65	0.13 0.11	0.087	21 ± 1°	58 ± 1%	96/1	Falconbridge #1 Diesel
Dec 14	3	0.15	5	N.D.	110	65	0.09 0.09	0.074	22.7 ± 0.5°	61 ± 1%	101/1	1990
Dec 15	2	0.16	22	N.D.	140	80	0.08 0.10	0.078	22.9 ± 0.8°	63 ± 1%	96/1	Jet A-1
Dec 16-A	2	N.M.	6	N.M.	N.M.	N.M.	0.12	0.106	22.0 ± 1°	62 ± 1%	71/1	Jet A-1
Dec 16-B,C	5	0.2	N.M.	N.M.	80	45	0.15	0.072	23.0°	61%	104/1	Falconbridge #1 Diesel
										AVERAGE	$\frac{94 \pm 13}{1}$	

* Calculated assuming Raw Exhaust is 7.5% CO_2

N.M. Not Measured

N.D. None Detected

Properties of the Diesel Fuels

The three fuels used in this study were subjected to several different analyses so that the properties of the exhaust could be compared with those of the fuel that was burned in the diesel engine. The properties and composition of the three fuels are given in Tables 3 and 4.

The results in these tables show that the properties of the Falconbridge #1 diesel fuel are intermediate between those of the Jet-A1 and the 1990 fuels, ie., only three of the test results for the Falconbridge #1 diesel fuel (the pour point, the Cetane Index and the percent napthenes) do not fall between the corresponding values for the Jet-A1 and the 1990 fuels.

The results in Tables 3 and 4 also show that there is not a great deal of difference between the Jet-A1 and the Falconbridge #1 diesel fuel. For example, the density, the boiling ranges, the kinematic viscosity, the Ramsbottom Carbon, the Cetane Index, the composition and even the PAH concentrations in these two fuels are almost identical. Some of the other properties of these two fuels such as the pour point, the cloud point and the ash content do differ. However, these properties are not thought to have large effects on the quality of the exhaust.

The 1990 fuel on the other hand, is significantly different from the other two fuels. The 1990 fuel is more dense, it contains a small amount of lower boiling point material and is much richer in the high boiling hydrocarbons than the other fuels. In addition, it has a much higher percent sulfur, kinematic viscosity, cloud point, the highest Ramsbottom Carbon and the lowest Cetane Index.

Finally, the composition of the 1990 fuel is very different from the other two fuels. Although the percent napthenes is

Table 3. Properties of the fuels used in the fuel tests at Lockerby Mine, December, 1982

Fuel	Jet A-1 Fuel	Falconbridge #1 Diesel	1990 Fuel
Density 15°C	0.817	0.823	0.879
Distilation, D86, °C			
IBP	174	176	169
5	185	189	188
10	189	194	196
20	193	203	215
30	198	210	232
40	204	216	248
50	209	222	265
60	215	228	283
70	221	235	302
80	220	243	324
90	240	252	347
FBP	270	280	380
Residue, vol. %	1	1	1
Sulphur/wt. %	0.0067	0.085	0.49
Kinematic Viscosity cSt @ 40°C	1.42	1.65	2.77
Cloud Point °C	<-55	-42	-7
Pour Point °C	<-55	-40	-43
Ash, wt. %	nil	0.003	<0.001
Water and Sediment	nil	trace	trace
Ramsbottom Carbon wt. % on 10% bottoms	0.07	0.05	0.20
Cetane Index	44.9	46.7	37.7
Estimated Hydrocarbon Type by Chemical Ionization (GC.MS)			
Paraffins wt. %	48.3	43.5	40.9
Olefins wt. %	0	0	0
Naphthenes wt. %	26.6	27.5	25.5
Aromatics wt. %	25.0	28.9	33.6

Table 4. The PAH concentrations in the three fuels.

Concentration in ppb.

PAH	Jet-A-1 Fuel		Falconbridge #1 Diesel		1990 Fuel	
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Pyrene	112	184	123	209	1525	934
Fluoranthene	4.56	6.65	3.19	20.3	141	122
Benzo(a)anthracene*	52.2	65.2	298	269	10574	3746
Benzo(e)pyrene	12.7	4.59	36.9	9.06	5057	4077
Perylene	0.14	0.27	0.25	0.21	74	129
Benzo(k)fluoranthene	0.49	0.43	0.66	0.30	135	139
Benzo(a)pyrene*	0.39	0.12	0.32	0.39	190	177
Benzo(ghi)perylene*	8.93	3.20	6.68	13.6	2266	1084
Dibenzo(a,h)anthracene*	3.31	5.78	4.51	2.08	906	887
Dibenzo(def,mno)chrysene	0.08	0.09	0.27	0.24	7.10	8.36
Naptho(1234,def)chrysene*	1.29	3.76	0.94	0.56	128	511
Benzo(rst)pentaphene*	0.29	0.40	0.07	0.56	21.50	41.8
Total PAHs	196ppb	274ppb	475ppb	525ppb	21026ppb	11857ppb
Total-pyrene	84.4ppb	90.5ppb	352ppb	316ppb	19500ppb	10923ppb
Total Carcinogens	66.4ppb	78.5ppb	310ppb	286ppb	14086ppb	6447ppb

* Carcinogenic PAHs

almost identical in all three fuels, the 1998 fuel has 6 percent and 15 percent less paraffins than the Falconbridge #1 fuel and the Jet-A1 fuel, respectively. An even more striking difference between the 1998 and the other fuels is in the percent aromatics. The 1998 fuel is much (almost 20 percent) richer in aromatic hydrocarbons than the Falconbridge #1 fuel and is 35 percent higher in aromatics than the Jet-A1 fuel. Thus, one would expect that the 1998 fuel would also be richer in PAHs which are a class of aromatic hydrocarbons. The results in Table 4 show that this is indeed the case. The individual PAHs in the 1998 fuel are from 7.4 to 523 times more concentrated than the PAHs in the Falconbridge #1 diesel fuel and are from 8.3 to 732 times more concentrated than those in the Jet-A1 fuel. A comparison of the average Total PAHs and the Total Carcinogens in the three fuels confirms the conclusions based on the concentrations of the individual PAHs. For example, the Total PAHs in the 1998 fuel are 33 times higher than those in the Falconbridge #1 fuel and 70 times higher than the Total PAHs in the Jet-A1 fuel. This same difference is observed when one compares the Total Carcinogenic PAHs in the three fuels. The 1998 fuel has 34 times more carcinogens than the Falconbridge #1 fuel and 142 times more carcinogens than the Jet-A1 fuel.

The results in Tables 3 and 4 show that the three fuels are different. More important however, the PAH concentrations in the three fuels are very different. This means that these three fuels will provide us with a good test of the hypothesis that "the PAHs in the exhaust are to a large degree, the unburned residue of the PAHs in the fuel". If this is the case, one would expect the exhaust from a diesel burning the 1998 fuel to have the highest concentration of PAHs and the highest mutagenicity. The exhaust from the diesel burning the Jet-A1 fuel on the other hand, would contain the fewest PAHs and be the least mutagenic.

PAH Concentrations in the Exhaust

Duplicate Hi Vol exhaust samples were collected at the sampling sites when the three different fuels, the Falconbridge #1 diesel, the Jet-A1 and the 1998 fuels were burned in the F8L-714 Deutz diesel. The Hi Vol exhaust samples were extracted and analyzed for PAHs using our standard technique (5). The results from these analyses are presented in Table 5. In addition to the PAH concentrations in the exhaust samples from the three different fuels (columns 1-6), Table 5 presents the PAH concentrations found in an exhaust sample collected at the end of the test program when the diesel was again burning Falconbridge #1 diesel fuel (column 7) and an intake air sample (column 8). This final exhaust sample was collected to determine whether a significant change had occurred when the diesel engine was run on the other fuels. The intake air sample was collected to give a background PAH level at the test site.

A comparison of the PAH concentrations in the exhaust and intake air samples shows that the PAHs are much more concentrated in the exhaust than they are in the intake air. In fact, the concentrations of the individual PAHs in the exhaust range from a low of 8.98 to a high of 46.4 times the PAH concentrations in the intake air and the average Total PAHs downstream from the diesel is 7.5 times the Total PAHs in the intake air. It is worth noting that the ratio of the (PAHs in the mine environment/PAHs in the intake air) is probably greater than 7.5/1.8. The PAH concentrations found in the single intake air sample collected at Lockerby mine were considerably higher than the average PAH concentrations found in Sudbury air between 1988 and 1982 (7). If the average PAH concentrations in Sudbury air are used to calculate the amount of PAHs added to the mine environment by the diesel, the PAHs in the mine would be approximately 13 times more concentrated than those in the intake air. Finally, the PAHs in the mine environment were

Table 5. The PAH concentrations in the exhaust air samples collected when three different diesel fuels were burned.

Concentration in ng/m^3

PAH	Falconbridge #1 Diesel		Tar Sands-1990		Jet A-1		Falconbridge #1 Diesel	Intake Air
	Dec 13-A	Dec 13-B	Dec 14-A	Dec 14-B	Dec 15-A	Dec 15-B	Dec 16-B	
Pyrene	117	79.8	138	156	260	119	138	16.5
Fluoranthene	3.86	3.04	5.40	7.89	9.00	6.65	33.1	0.99
Benzo(a)anthracene*	45.0	7.90	13.2	15.4	99.8	51.1	84.5	8.04
Benzo(e)pyrene	21.2	12.6	23.7	36.4	38.4	19.8	35.9	5.28
Perylene	0.57	0.64	0.44	0.48	1.94	0.84	1.55	0.09
Benzo(k)fluoranthene	2.97	2.71	4.09	4.58	7.36	4.53	9.62	0.58
Benzo(a)pyrene*	1.64	3.02	3.42	1.60	5.22	4.36	6.49	0.14
Benzo(ghi)perylene*	3.63	4.50	7.69	5.49	17.0	8.80	16.0	0.79
Dibenzo(a,h)anthracene*	3.26	1.95	3.58	6.33	4.12	4.48	8.91	0.84
Dibenzo(def,mno)chrysene	1.00	1.00	0.69	0.59	1.57	1.49	2.34	0.07
Naptho(1234,def)chrysene*	5.04	0	2.98	0.54	9.97	4.07	4.04	0.55
Benzo(rst)pentaphene*	1.01	0.65	0.93	0.86	1.78	1.16	2.42	0.19
Total PAHs	206	118	204	236	456	226	343	34.1
Total-pyrene	89.2	38.0	66.1	80.2	196	107	205	17.5
Total Carcinogens	59.6	18.0	31.8	30.2	138	74.0	122	10.5
% CO_2	0.087	0.087	0.074	0.074	0.078	0.078	0.072	-
NO_2 ppm	0.17	0.17	0.15	0.15	0.16	0.16	not measured	-
Wgt. of Extract (mg.)	56.17	56.13	27.49	22.94	29.28	42.09	51.90	5.80
Hi Vol. Sample No.	3 (Left)	4 (Right)	3 (Left)	4 (Right)	3 (Left)	3 (Left)	3 (Left)	-
Scoop Tram Operator	1 + 2	1 + 2	2	2	2	2	1	-
Ventilation (cfm)	28,500	28,500	29,600	29,600	28,700	28,700	28,000	-

collected when the ventilation was approximately 155 cfm/brake horsepower. If the ventilation had been at the legal limit of 100 cfm/brake horsepower, the PAH concentrations in the mine air would be approximately 20 times higher than those in the intake air. Obviously, the diesel adds a significant amount of PAHs to the mine environment.

An examination of the PAH concentrations in the exhaust from the three fuels (columns 1 through 7 of Table 5 and the synopsis in Table 6) show that there is very little difference in the PAH levels in the exhaust when the different fuels are burned in the diesel. All of the ratios of the individual PAHs in the exhaust from the different fuels are close to unity. For example, the ratios of the concentrations of the individual PAHs in the Jet-A1 and the Falconbridge #1 fuels range from 0.76 to 2.85 and the corresponding ratios for the 1990 and the Falconbridge #1 fuel range from 0.32 to 1.92.

The same trends are observed when one examines the average ratios for the Total PAHs, the Total-pyrene and the Carcinogenic PAHS, Table 6. In fact, the difference between the average Total PAHs in the exhaust from the three fuels is less than the difference between the PAH concentrations found when the Falconbridge #1 fuel was burned at the start and the end of the test period, ie., the ratio of the Total PAHs in the exhaust from the three fuels is 162/220/341 (1.00/1.36/2.10) whereas the ratio of the Total PAHs in the exhaust collected at the beginning and the end of the test period when the diesel was burning Falconbridge #1 fuel is 162/343 or 1.00/2.12. The same general trend is seen with the Total-pyrene and the Total Carcinogens. The average Total-pyrene ratio for the three fuels is 64/73/152 (1.00/1.15/2.39) whereas the corresponding ratio for the PAHs found when the Falconbridge #1 diesel fuel was burned at the beginning and the end of the test period

Table 6. Average PAHs and the PAH ratios found in the exhaust from three different fuels

	Average Total PAHs ng/m^3	Average Total-pyrene ng/m^3	Average Total Carcinogens ng/m^3
Initial Falconbridge #1 Diesel	162	64	39
Jet-A1	220	73	31
1990	341	152	106
Final Falconbridge #1 Diesel	343	205	122
$\left(\frac{1990}{\text{Initial Falconbridge \#1}}\right)$	1.36	1.15	0.80
$\left(\frac{\text{Jet-A-1}}{\text{Initial Falconbridge \#1}}\right)$	2.10	2.39	2.73
$\left(\frac{\text{Final Falconbridge \#1}}{\text{Initial Falconbrdige \#1}}\right)$	2.12	3.20	3.10

was 64/285 or 1.00/3.20. The corresponding ratios for the Total Carcinogens in the exhaust were 39/31/106 (1.00/0.80/2.73) and 39/122 (1.00/3.10), respectively.

These results obviously indicate that the concentrations of the PAHs in the exhaust are less dependent on the concentration of the PAHs in the fuel than they are on the state of the diesel used in the test. Obviously, modifying the fuel burned in the diesel will not be a successful strategy for reducing the concentrations of PAHs in diesel exhaust.

In fact, it is worth noting that the lowest concentrations of PAHs were found in the exhaust when the diesel was operating on the Falconbridge #1 diesel fuel. The next lowest concentrations of PAHs were found in the exhaust when the 1998 fuel was used. In fact, the PAH concentrations in the exhaust from the 1998 fuel were only slightly higher than those observed when the Falconbridge #1 diesel fuel was burned (the ratios of the Total PAHs, the Total-pyrene and the Total Carcinogens are only 1.00/1.36, 1.00/1.15 and 1.00/0.80, respectively) in spite of the fact that the 1998 fuel had by far the highest concentrations of PAHs, ie., the Total PAHs in the 1998 fuel were 33 times higher than those in the Falconbridge #1 fuel.

It is also interesting to note that the highest concentrations of PAHs were found in the exhaust from the Jet-A1 fuel even though this fuel had the lowest concentrations of PAHs, ie., the Total PAHs were 2.1 times more concentrated in the Falconbridge #1 and 70 times more concentrated in the 1998 fuel than they were in the Jet-A1 fuel.

Obviously, these results indicate that there is no strong relationship between the PAHs in the fuel and those in the exhaust from a diesel. This clearly demonstrates that modifying the diesel fuel is not a useful strategy for reducing the concentrations of the PAHs in a mine environment. Thus, future efforts to further reduce the concentrations of these pollutants

should be centered on the development and testing of new exhaust treatment devices and/or types of engines.

Mutagenicity of the Exhaust

The mutagenicities of the exhaust extracts from the Hi Vol filters collected when the F8L-714 Deutz diesel was operating on the three different fuels, were determined using several different Salmonella tester strains in the Ames bioassay (5).The details of the sampling and the specific mutagenicites (the average revertants/microgram of the Hi Vol filter extract) are shown in Table 7. The corresponding revertants/m^3 in the air at the sampling site are given in Table 8. The mutagenicities presented in Tables 7 and 8 were calculated from the results obtained in the Ames bioassays by Mr. A. Horton of the Ontario Research Foundation in Mississauga, Ont.. Mr. Horton's results are in Appendix 1.

The results in Table 7 show that the specific mutagenicity of the exhaust is not affected significantly by the type of fuel burned in the engine. For example, the specific mutagenicities of the exhaust extracts from the Falconbridge #1 and the Jet-A1 fuels are almost identical for each of the tester strains used in the Ames bioassay. The only differences in the results for these two fuels are that 1) the average specific mutagenicity for the Jet-A1 extract is slightly (26 percent) greater when the TA98-S9 tester strain is used in the analysis and 2) the very weak response found when one of the Jet fuel extracts was analyzed with the TA98NR tester strain. These differences are small and the authors do not believe them to be significant.

There is a small difference between the specific mutagenicities of the exhaust extracts when the Falconbridge #1 and the 1998 fuels were burned in the diesel. In fact,

Table 7. The specific mutagenicity of the diesel exhaust extracts from Hi Vol filters collected downstream from a diesel burning different fuels.

Type of Fuel	Sample	Wgt. of Extract (mg)	Volume of air sampled (m^3)	Specific Mutagenicity with Salmonella Strain				
				TA98-S9	TA98+S9	TA98NR	TA98-1,8 DNP6	TA98NR -1,8-DNP6
Falconbridge #1 Diesel	Dec 13-C	43.9	113.9	0.20	N.M.[a]	-ve[b]	-ve	-ve
Falconbridge #1 Diesel	Dec 16-C	49.3	74.3	0.19	0.30	-ve	-ve	N.M.
Jet A-1	Dec 15-C	40.4	115.8	0.29	N.M.	0.14	-ve	-ve
Jet A-1	Dec 16-A	51.2	110.6	0.20	0.32	-ve	-ve	N.M.
1990	Dec 14-C	54.4	121.9	0.52	N.M.	0.21	0.15	-ve
1990	Dec 14-D	47.6	101.0	0.17	0.27	-ve	-ve	N.M.
1990	Dec 14-E + Dec 14-F	119.3	224.7	0.52	N.M.	0.17	N.M.	N.M.

a. N.M. means not measured.

b. -ve indicates that no mutations were observed.

Table 8. The mutagenicity of the air downstream from a diesel burning three different fuels in Lockerby mine, December 1982.

Type of Fuel	Sample	Hi Vol Location	Scoop Tram Operator	Average Revertants/m^3 with Salmonella strain[a].				
				TA98-S9	TA98+S9	TA98NR	TA98-1.8-DNP6	TA98NR-1,8-DNP6
Falconbridge #1 Diesel	Dec 13-C	4	1	77.1	NM	0	0	0
Falconbridge #1 Diesel	Dec 16-C	4	1	126	199	0	0	NM
Average Falconbridge #1 Diesel				102	199	0	0	0
Jet A-1	Dec 15-C	4	2	101	NM	48.8	0	0
Jet A-1	Dec 16-A	4	1	92.6	148	0	0	NM
Average Jet A-1				97	148	24	0	0
1990	Dec 14-C	4	1	232	NM	93.7	66.9	0
1990	Dec 14-D	4	1	80.1	127	0	0	NM
1990	Dec 14-E + Dec 14-F	3,3	1,1	276	NM	90.3	NM	NM
Average 1990				254[b]	127	92[b]	67[b]	0

a. Calculated from the data in Table 7.
N.M. - not measured

b. These results were calculated using the results obtained from samples Dec 14-C and Dec 14-E + Dec 14-F

the specific mutagenicity was 2.67 times higher when the 1990 extract was analyzed using the TA98-S9 tester strain. In addition, the specific mutagenicity of the 1990 filter extract was higher when the TA98NR and the TA98-1,8-DNP6 tester strains were used in the Ames analysis. Thus, the 1990 Hi Vol filter extracts are somewhat more mutagenic than those from either the Falconbridge #1 or the Jet-A1 fuels. Although the increase in the mutagenicity of the exhaust extracts with the 1990 fuel seems significant, the change is probably small considering that 1) the specific mutagenicity of the 1990 exhaust extract is lower than that for the Falconbridge #1 fuel when the TA98+S9 tester strain is used in the analysis, 2) identical responses were obtained with the TA98NR-1,9-DNP6 tester strain, 3) the 1990 fuel has 33 times more PAHs and 4) has very different properties than the Falconbridge #1 diesel fuel. Thus, the specific mutagenicities of the exhaust extracts from all three fuels are similar regardless of the tester strain used in the Ames analysis and one must conclude that there is very little change in the specific mutagenicity of the exhaust when different fuels are burned in the Deutz diesel.

The same general conclusion is required when one examines the average mutagenicity (the average revertants/cubic meter) of the air collected downstream from the diesel burning the three different fuels. The average revertants/m^3 in the air downstream from the Deutz diesel burning the Falconbridge #1 and the Jet-A1 fuels, Table 8, are again identical within the limits of the analysis regardless of the Salmonella tester strain used in the Ames analysis. The only exception is the very weak positive response found using the TA98NR tester strain with one of the Jet-A1 exhaust extracts. We do not believe that this constitutes a significant difference.

The average mutagenicity of the air collected downstream from a diesel burning the 1990 diesel fuel on the other hand,

appears to be slightly higher than the mutagenicities of the air downstream from a diesel burning the Falconbridge #1 or the Jet-A1 fuels. Although the mutagenicity of the air is slightly lower when the TA98+S9 tester strain is used, it is identical when TA98NR-1,8-DNP6 is used and is slightly higher (the mutagenicity with TA98-S9 is 2.49 times higher, the response with TA98NR is 1.88 times higher and one positive response was obtained with the TA98-1,8-DNP6 tester strain) when the other tester strains are used in the Ames analysis. Although the mutagenicity of the air collected downstream from the Deutz diesel is slightly more mutagenic when the 1990 fuel is burned in the diesel, the differences are small and one must again conclude that the type of fuel burned in the engine does not influence to any great extent, the mutagenicity of the exhaust or the mine air downstream from a diesel.

The Effect of Changing the Operator

The results of the mutagenicity study are interesting for another reason. Two of the samples (Dec 15-C and Dec 16-A) used in the mutagenic testing of the exhaust extracts from the Jet-A1 fuel were collected when different scoop tram operators were driving the diesel. Since the environmental conditions at the sampling sites were similar and the samples were collected at the same sampling site, Tables 1 and 2, the results from these two samples give us some indication as to how changing the operators affects the mutagenicity of the exhaust. In fact, the results from the two samples are very similar, ie., the specific mutagenicity only changed from 0.20 to 0.29, when the drivers changed. This change is almost within the experimental error of the Ames analysis and thus it appears that changing the scoop tram operator does not affect the mutagenicity of the exhaust significantly. This test was valid because one of the operators was more aggressive,

ie., he consistently pushed the diesel harder during the lug down and had slightly shorter duty cycles.

Types of Mutagens in the Exhaust

The relative magnitudes of the mutagenic responses found with the different tester strains in the Ames analysis can indicate the type of mutagen that is present in the exhaust. The results in Tables 7 and 8 indicate that the exhaust extracts from all three fuels are more mutagenic when the enzyme S9 is added to the TA98 tester strain. In fact, the ratio of the mutagenicities found with and without S9 added to the TA98 tester strain were 1.54/1.00, 1.22/1.00 and 1.59/1.00 for the exhaust extracts and 1.95/1.00, 1.53/1.00 and 1.59/1.00 for the air downstream from the diesel burning the Falconbridge #1, the Jet-A1 and the 1990 fuels, respectively. The greater reponse with the TA98+S9 indicates that the exhaust from the Deutz diesel used in this test contains more indirect-acting mutagens than direct-acting mutagens. This means that there is a significant concentration of the unaltered PAHs (polynuclear aromatic hydrocarbons that have not been oxidized or nitrated to nitro-PAHs) in the exhaust. This result is different from those obtained in our previous studies. Usually, the response with the TA98+S9 tester strain is approximately 20 percent lower than that observed with TA98-S9 tester strain.

Nitro PAHs produce a very strong (positive) response with TA98-S9 whereas they give only weak or negative responses when they are tested with certain nitroreductase-deficient tester strains, ie., a particular nitro-PAH will give a small or negative response with one or more of the TA98NR, the TA98-1,8-DNP6 or the TA98NR-1,8-DNP6 tester strains. The smaller and negative responses found with the nitroreductase-deficient tester strains indicate that the diesel used in these tests also emits nitro-PAHs, ie., the reduced revertants/m^3 found

with these tester strains is observed because some of the nitro-PAHs that produced the positive response with the TA98-S9 tester strain, do not give a positive response with these other tester strains.

The magnitude of the mutagenic response with the various nitroreductase-deficient tester strains can give some indication of the type of nitro-PAH in the sample. For example, the TA98-1,8-DNP6 tester strain does not respond to most dinitro-PAHs but it does give a positive response with mononitro-PAHs. The responses observed when the TA98-1,8-DNP6 tester strain is used in the Ames analysis of the exhaust extracts from the Jet-A1 and the 1998 fuels are smaller than the responses obtained with the TA98NR tester strain. This suggests that dinitro-PAHs are present in the exhaust from these fuels. The smaller (negative) response with the TA98NR-1,8-DNP6 tester strain which does not respond to nitro-PAHs, indicates that there are both mononitro and dinitro-PAHs in the exhaust extract. The negative reponses found when the exhaust extract from the Falconbridge #1 diesel fuel was tested with the nitro-reductase deficient tester strains suggests that nitro-PAHs are also present in the exhaust from this fuel. However, the negative response obtained with all three of these tester strains does not allow us to comment on the relative amounts of the mononitro and the dinitro-PAHs in the sample.

The results of the mutagenic screening have shown 1) that the mutagenicity of the exhaust and the air downstream from a Deutz diesel is not altered significantly by the type of fuel burned in a F8L-714 Deutz diesel and 2) that the exhaust from the Deutz diesel used in these experiments is richer in the simple PAHs such as those assayed in the PAH analysis, and contains less of the nitro-PAHs than normal. Although the weak or negative responses found with the nitroreductase-deficient tester strains do not allow us to comment on the

relative concentrations of the mononitro and dinitro-PAHs in the exhaust from this diesel with any certainty, it appears that both mononitro and dinitro-PAHs are present in the exhaust from this diesel.

Other Effects of Changing the Fuel

Although the exhaust from the 1998 fuel was slightly more mutagenic than the exhaust from the other fuels, changing the fuel burned in the diesel did not alter the amounts of the PAHs or the mutagenicity of the mine air collected downstream from the diesel significantly. However, changing the fuel did alter the character of the exhaust in a noticable way. The exhaust from the Falconbridge #1 diesel fuel had the characteristic odour that is normally associated with the burning of diesel fuels. The exhaust from the Jet-A1 fuel on the other hand, had a sharper more penetrating odour than the exhaust from the Falconbridge #1 fuel and caused some irritation in the eyes and throat if one remained downstream from the diesel for extended periods of time. When the 1998 fuel was burned in the diesel, the air was much harder to breathe. Both the samplers and the scoop tram operators had considerable problems with eye and throat irritation when the 1998 fuel was used. It is not clear whether the problem with the eyes and throat was associated with the much higher sulfur content of the 1998 fuel or whether this problem was the result of the higher aromatic content of the fuel. If the eye and throat problems arise from the higher sulfur content of the fuel, using large quantities of this fuel may not cause an environmental or health problem because the sulfur content of a diesel fuel can be reduced significantly in the refining process. If the irritation is the result of the higher aromatic content of the fuel however, this fuel would have to be modified before it could be put into widespread use. This problem would

be severe if the 1998 fuel were used extensively above ground in a crowded city. It would cause a very severe problem if it were used in enclosed environments like those found in underground mines.

In conclusion, The Falconbridge #1 diesel fuel appears to be the best of the three fuels that were examined in this study. This is because the exhaust from the Falconbridge #1 diesel fuel had on the average 1) the lowest concentrations of PAHs, 2) was the least mutagenic and 3) was the most acceptible from the worker's point of view, ie., had the least obnoxious smell and did not cause any eye or throat irritation.

CONCLUSIONS

This study has determined how a change in fuel affects the exhaust from an F8L-714 Deutz diesel operating on a simulated LHD duty cycle in an underground nickel mine in the Sudbury area. Although the exhaust was slightly more mutagenic when the 1998 or "Tar Sands" fuel was burned in the diesel, the results demonstrate that changing from a low PAH fuel to a high PAH fuel does not alter PAH concentrations or the mutagenicity of the exhaust extracts or of the air downstream from the diesel significantly. In fact, it appears that the day to day variations in the diesel cause a greater change in the exhaust than changing the fuel. It is worth noting that the work described in this report provides a good test of the effect of changing the fuel because the three fuels used in these experiments are very different. For example, the Jet-A1 fuel had less than half of the PAHs found in the Falconbridge #1 fuel and the 1998 "Tar Sands" fuel had 33 times more PAHs than the Falconbridge #1 fuel. In addition, the 1998 fuel had very different properties and composition than the other two fuels used in these tests.

This study has also <u>suggested</u> that changing drivers on the scoop tram does not have a major effect on the mutagenicity of the exhaust.

On the basis of this work, it appears that a fuel like the Falconbridge #1 fuel is best for underground mines. Although the fuel does not affect the concentrations of the PAHs and the mutagens in the exhaust significantly, a Falconbridge #1 type of fuel is better because the exhaust from this fuel does not cause eye and throat irritation. The exhaust from the Jet-A1 fuel on the other hand is mildly irritating and the exhaust from the 1998 "Tar Sands" fuel causes significant eye and throat irritation. Unfortunately, we do not know whether this is due to the much higher sulfur content in the 1998

fuel or whether this is the result of the higher concentrations of aromatics in the fuel. If the irritation is due to the higher concentrations of aromatics, the 1990 fuel would not be suitable for use in underground mines and would even cause problems above ground if it were used extensively in large cities. One should remove most of the sulfur from a batch of the Tar Sands fuel and determine whether the sulfur compounds caused the eye and throat irritation.

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APPENDIX I

TABLE 1 - Ames Mutagenicity Plate Incorporation Assay Results for DCM Extractables from Hi-Vol Filter #14R (Regular Fuel)

Concentration Filter Extract µg/Plate	S-9 Mix +/-	Salmonella Tester Strains															
		TA-98 Histidine Revertants			(AV)	TA-98 NR Histidine Revertants			(AV)	TA-98 1,8DNP$_6$ Histidine Revertants			(AV)	TA-98 NR/1,8DNP$_6$ Histidine Revertants			(AV)
600	-	171	177	149	(166)	68	69	84	(74)	64	60	55	(60)	15	22		(19)
500	-	143	155	141	(146)	73	65	60	(66)	48	37	62	(49)	14	17		(16)
450	-	132	123	123	(126)	75	55	64	(65)	39	58	41	(46)	12	23		(18)
400	-	153	162	143	(153)	61	62	68	(64)	49	67	65	(60)	12	22		(17)
350	-	91	96	77	(88)	58	46	51	(52)	23	40	32	(32)	15	16		(16)
300	-	93	92	92	(92)	34	51	45	(43)	42	59	41	(47)	23	25		(24)
250	-	69	88	95	(84)	44	49	44	(46)	34	31	41	(35)	18	18		(18)
200	-	80	84	85	(83)	40	46	40	(42)	51	44	40	(45)	20	20		(20)
150	-	96	67	68	(77)	44	42	34	(40)	47	37	41	(42)	21	9		(15)
100	-	62	85	84	(77)	32	27	40	(33)	35	39	42	(39)	18	18		(18)
75	-	52	58	56	(55)	28	36	28	(31)	34	44	55	(44)	11	17		(14)
50	-	55	54	65	(58)	45	37	29	(37)	42	40	56	(46)	22	13		(18)
Control 0					(39)				(30)				(21)				(13)
Specific Activity		0.20				Neg				Neg				Neg			

DCM Extractables (SOF) 43.9 mg

TABLE 2 - Ames Mutagenicity Plate Incorporation Assay Results for DCM Extractables from Hi-Vol Filter #32R (Regular Fuel)

Concentration Filter Extract µg/Plate	Salmonella Tester Strains															
	TA-98 Without S-9 Histidine Revertants			(AV)	TA-98 With S-9 Histidine Revertants			(AV)	TA-98 NR Without S-9 Histidine Revertants			(AV)	TA-98 1,8DNP6 Without S-9 Histidine Revertants			(AV)
1000	182	216	185	(191)	241	262	266	(256)	114	104	111	(109)	64	55	44	(55)
800	173	179	180	(177)	261	245	241	(249)	98	92	72	(87)	55	48	58	(54)
600	168	154	174	(166)	221	244	217	(227)	81	85	87	(84)	55	50	52	(52)
500	162	170	186	(173)	236	216	253	(235)	99	92	75	(89)	42	49	53	(48)
400	152	150	179	(160)	227	187	235	(216)	86	76	68	(77)	47	50	41	(46)
300	151	154	131	(145)	172	134	182	(179)	55	72	75	(67)	44	48	45	(46)
200	130	122	104	(119)	168	159	154	(160)	61	68	57	(62)	49	48	43	(47)
100	99	101	93	(98)	129	103	131	(121)	61	55	47	(54)	36	46	32	(38)
Control 0				(58)				(54)				(47)				(24)
Specific Activity	0.19				0.30				Neg				Neg			

DCM Extractables (SOF) 49.3 mg

ORF

TABLE 3 - Ames Mutagenicity Plate Incorporation Assay Results for DCM Extractables from Hi-Vol Filter #28R (Jet Fuel)

Concentration Filter Extract µg/Plate	Salmonella Tester Strains															
	TA-98 Without S-9 Histidine Revertants			(AV)	TA-98 NR Without S-9 Histidine Revertants			(AV)	TA-98 1,8DNP$_6$ Without S-9 Histidine Revertants			(AV)	TA-98 NR/1,8DNP$_6$ Without S-9 Histidine Revertants			(AV)
600	197	194	246	(212)	107	123	110 *	(113)	15	28	37	(25)	17	16		(17)
500	232	203	216	(217)	89	74	84	(82)	37	26	33	(32)	11	21		(16)
450	181	190	172	(181)	68	66	82	(72)	14	22	15	(17)	15	13		(14)
400	249	264	253	(255)	95	97	103 *	(98)	22	17	36	(25)	21	17		(19)
350	103	107	121	(110)	51	67	60	(59)	5	17	2	(8)	22	12		(17)
300	102	141	143	(129)	63	64	70 *	(66)	30	42	20	(31)	22	17		(20)
250	107	115	96	(106)	57	49	76	(61)	31	37	33	(34)	16	20		(18)
200	96	100	127	(108)	61	65	62 *	(63)	45	31	43	(40)	15	20		(18)
150	89	94	76	(86)	42	38	37	(39)	23	35	26	(28)	13	8		(11)
100	84	84	73	(80)	43	52	51 *	(49)	34	28	23	(28)	16	17		(17)
75	86	69	86	(80)	47	42	37	(42)	31	34	24	(30)	21	19		(20)
50	57	68	67	(64)	39	35	43 *	(39)	28	20	26	(25)	15	20		(12)
Control 0				(39)				(30)				(21)				(13)
Specific Activity	0.29				0.14*				Neg				Neg			

DCM Extractables (SOF) 40.4 mg

ORE

TABLE 4 - Ames Mutagenicity Plate Incorporation Assay Results
for DCM Extractables from Hi-Vol Filter #30R (Jet Fuel)

Concentration Filter Extract µg/Plate	Salmonella Tester Strains															
	TA-98 Without S-9 Histidine Revertants			(AV)	TA-98 With S-9 Histidine Revertants			(AV)	TA-98 NR Without S-9 Histidine Revertants			(AV)	TA-98 1,8DNP6 Without S-9 Histidine Revertants			(AV)
1000	207	175	202	(195)	279	240	221	(247)	62	82	57	(67)	40	57	54	(50)
800	191	204	189	(195)	268	275	226	(256)	83	52	89	(75)	56	72	59	(62)
600	179	166	164	(170)	221	276	253	(250)	54	79	82	(72)	61	70	62	(64)
500	164	169	159	(164)	220	232	230	(227)	71	61	77	(70)	54	35	70	(53)
400	150	165	160	(158)	221	223	249	(231)	63	81	74	(73)	60	11	29	(33)
300	131	140	142	(138)	163	204	179	(182)	71	99	78	(83)	27	34	14	(25)
200	111	109	114	(111)	151	169	184	(168)	71	74	59	(68)	23	25	24	(24)
100	115	97	95	(102)	131	113	139	(128)	49	61	60	(57)	23	22	24	(23)
Control 0				(58)				(54)				(47)				(24)
Specific Activity	0.20				0.32				Neg				Neg			

DCM Extractables (SOF) 51.2 mg

ORF

TABLE 5 - Ames Mutagenicity Plate Incorporation Assay Results
for DCM Extractables from Hi-Vol Filter #18R (1990 Tar Sands Fuel)

Concentration Filter Extracts µg/Plate	Salmonella Tester Strains															
	TA-98 Without S-9 Histidine Revertants			(AV)	TA-98 NR Without S-9 Histidine Revertants			(AV)	TA-98 1,8DNP$_6$ Without S-9 Histidine Revertants			(AV)	TA-98 NR/1,8DNP$_6$ Without S-9 Histidine Revertants			(AV)
1000	345	337	375	(352)	142	147	142	(144)	92	84	74	(83)	23	15	19	(19)
800	346	318	369	(344)	148	133	105	(129)	90	102	96	(96)	15	15	13	(14)
600	342	299	319	(320)	128	143	133	(135)	103	73	104	(93)	15	15	17	(16)
500	284	303	331	(306)	108	130	140	(126)	94	82	75	(84)	15	16	21	(17)
400	260	298	274	(277)	111	101	122	(111)	72	91	83	(82)	13	21	15	(16)
300	279	231	249	(253)	102	112	114	(109)	80	61	62	(68)	11	17	29	(19)
200	215	201	204	(207)	100	95	83	(93)	47	35	44	(42)	16	11	25	(17)
100	131	144	127	(134)	59	63	86	(69)	24	35	39	(33)	10	16	14	(13)
50	97	105	107	(103)	32	64	68	(55)	34	29	29	(31)	14	16	14	(15)
Control 0				(29)				(35)				(14)				(11)
Specific Activity	0.52				0.21				0.15				Neg			

DCM Extractables (SOF) 54.4 mg

ORE

TABLE 6 - Ames Mutagenicity Plate Incorporation Assay Results
for DCM Extractables from Hi-Vol Filter #22R (1990 Tar Sands Fuel)

Concentration Filter Extract µg/Plate	Salmonella Tester Strains															
	TA-98 Without S-9 Histidine Revertants			(AV)	TA-98 With S-9 Histidine Revertants			(AV)	TA-98 NR Without S-9 Histidine Revertants			(AV)	TA-98 1,8DNP6 Without S-9 Histidine Revertants			(AV)
1000	153	182	149	(161)	219	221	243	(227)	97	94	100	(97)	12	31	25	(23)
800	163	165	210	(179)	286	243	276	(268)	67	93	93	(84)	42	42	33	(39)
600	172	162	176	(170)	226	234	234	(231)	97	91	89	(92)	45	45	55	(48)
500	145	176	151	(157)	212	265	225	(234)	90	90	94	(91)	12	21	15	(16)
400	179	158	149	(162)	225	220	180	(208)	77	93	87	(86)	14	16	20	(17)
300	116	126	126	(123)	208	199	189	(198)	81	64	72	(72)	13	16	21	(17)
200	132	145	133	(136)	142	173	152	(156)	57	73	54	(61)	13	18	17	(16)
100	93	115	116	(108)	118	125	133	(125)	69	63	58	(63)	26	9	22	(19)
Control 0				(58)				(54)				(47)				(24)
Specific Activity	0.17				0.27				Neg				Neg			

DCM Extractables (SOF) 47.6 mg

ORF

TABLE 7 - Ames Mutagenicity Plate Incorporation Assay Results
for DCM Extractables from Hi-Vol Filters #21L & #17L (1990 Tar Sands)

Concentration Filter Extract µg/Plate	S-9 Mix	Salmonella Tester Strains									
		TA-98 Histidine Revertants				(AV)	TA-98 NR Histidine Revertants				(AV)
3000	-	284	334	297	Tox	(305)	152	148	166	Sl Tox	(155)
2400	-	344	266	370	Sl Tox	(327)	160	151	128		(146)
1800	-	262	313	344	Sl Tox	(306)	161	188	151		(167)
1500	-	266	264	373		(301)	110	154	131		(132)
1200	-	336	321	301		(319)	131	144	129		(135)
1000	-	283	307	297		(296)	102	111	125		(113)
800	-	285	309	304		(299)	114	121	130		(122)
600	-	287	367	374		(343)	106	138	155		(133)
500	-	123	124	128		(125)	90	103	80		(91)
400	-	130	128	118		(125)	67	66	73		(69)
350	-	145	114	106		(122)	62	58	68		(63)
300	-	128	120	158		(135)	83	59	68		(70)
250	-	93	113	102		(103)	56	42	64		(54)
200	-	107	127	88		(107)	72	75	51		(66)
150	-	82	103	76		(87)	56	57	39		(51)
100	-	79	75	92		(82)	45	49	49		(48)
80	-	45	57	44		(49)	33	40	40		(38)
40	-	37	46	52		(45)	26	25	23		(25)
Control 0	-					(35)					(22)

Specific Activity 0.52 0.17

DCM Extractables (SOF) 119.3 mg

ORE